COMPARATIVE EFFECTS OF THERMAL ENERGY TO PERSONNEL IN FLASH FIRES WHILE WEARING VARIOUS LEVEL A CHEMICAL PROTECTIVE CLOTHING (CPC) ENSEMBLES

Executive Development

Terry A. Bindernagel
Cleveland Fire Department
Cleveland, Ohio

An applied research project submitted to the National Fire Academy as part of the Executive Fire Officer Program

March, 2003

Abstract

The purpose of this research paper was to develop comparative data of effects of flash fire conditions on personnel while wearing various Level A chemical protective clothing (CPC) ensembles used by the Cleveland Fire Division.

Action research was utilized, and the following research questions were posed:

1) In simulated flash fire conditions, what ensembles perform best against flame impingement based on comparison of predicted degree of burns and total body burns to the wearer?
2) What hazards, other than the flash fire burns, can affect personnel wearing various CPC ensembles in thermal events?
3) Do the results of this testing suggest subjective analysis (both from generated reports and visible testing results) be applied to fireground tactics with potential for dual events, i.e. chemical and thermal?

With the cooperation of Dupont, tests simulating flash fire conditions were conducted in the Thermo-Man® laboratory. While wearing the various ensembles and subjected to flash fire conditions, the manikin measured heat energy that would be absorbed by the skin of personnel in similar situations.

Results showed that while burns to the torso were minimized, trauma to the head was a common factor. The material used in suit construction, polyethylene, dripped and flowed creating small pool fires on and around personnel. Overgarments lessened

the effect of flame impingement, but trapped byproducts of combustion.

The following recommendations from this research are; education of appropriate members of the Cleveland Fire Division be conducted to better understand the safety concerns of exposure to a thermal environment while wearing CPC. NFPA Technical Committees overseeing CPC performance standards are recommended to review required labeling of garments for better understanding of flash fire performance. The final recommendation is Technical Committees should review materials used in chemical ensembles and review training criteria for incidents with chemical and thermal potential for amendment to existing standards.

Table of Contents

Introduction

The Cleveland Fire Division serves a diverse industrial, technological and transportation corridor in a large urban section of Northeast Ohio. In the mid 1980’s, the Cleveland Fire Division trained and equipped a Hazardous Materials Response Team that initially served the City of Cleveland and 26 surrounding communities. As in the infancy of many new operative adventures, the equipment and training first obtained was not ideally suited for the end use. Throughout the existence of this unit, the Cleveland Fire Division has strived to refine the needs of the unit for the purposes of safety and functionality.

From the inception of equipping the team with chemical resistive equipment, clothing has been defined in terms of levels of protection. Per standards of the Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (Keegen,1999), the accepted levels are designated as A, B, C and D with Level A being the highest form of protection against chemical hazards. Level A is an ensemble designed to be selected when “the greatest level of skin, respiratory, and eye protection is required”(Keegen,1998,p. 1355). National Fire Protection Association (NFPA) chemical protective clothing (CPC) standards are more performance based than rigidly component based EPA standards (NFPA standard 1500, 1997). However, all standards have similar expectations in the intent of the performance of Level A garments. The expectations are that the chemical ensemble should protect you against the toxic vapor-to-skin contact hazards of a material. Potential thermal hazards contained within the same vapors have received a less critical consideration into CPC ensembles.

As hazardous material response became recognized as a specialized function within the Division, what also became apparent was a need for augmenting the chemical protection properties of CPC with thermal protection based on substances containing the dual hazards of toxicity and flammability. “Fire fighters must realize that no single combination of protective equipment and clothing is capable of protecting them against all hazards. Therefore, chemical-protective clothing should be used in conjunction with other protective methods” (NFPA standard 1500,1997,A-5-6). The potential of incidents with dual hazards of chemical and thermal protection has been further augmented by the recent warnings of response to suspected biological and/or chemical incidents with disguised secondary devices designed to inflict harm on responders by releasing thermal energy (Fire Engineering,1998,p. 68).

The purpose of this research project is to subject the various vapor protective chemical protective clothing ensembles the Cleveland Fire Department has used in hazardous material response to flash fire tests and record the thermal effects of the flash fire to the wearer of the ensemble.

This project employed action research. The research questions posed were:

1) In simulated flash fire conditions, what CPC ensembles perform best against flame impingement based on comparison

of predicted degree of burns and total body burns to the wearer?

2) What forms of harm, other than flash fire burns, can affect personnel wearing various CPC ensembles in thermal events?

3) Do the results of this testing suggest subjective analysis (both from generated reports and visible testing results) be applied to fireground tactics with potential for dual events, i.e. chemical and thermal?

Background and Significance

Local jurisdictions develop standard operating procedures based on accepted practices as recommended by various national standard associations (Cook,1998). The background of this research paper is based on the exploration of concepts that have contributed to CPC standards and use. These concepts have been incorporated into standards, which in turn have been used by local jurisdictions to develop operational procedures. The emphasis of this research paper is to determine if more significance should be placed on potential outcomes associated with the use of certain ensembles for personnel protection, and operating procedures adjusted for safety and greater awareness.

The following sections are dedicated to the specific areas of concern.

Physical properties of hazardous materials

The three physical states of matter are solid, liquid and gas. First responders can potentially encounter any combination of these physical states at an incident. For purposes of this research, concentration shall be placed on understanding the phases of movement between liquid and gas states.

Over ninety percent of organic hazardous compounds come from families with six carbons or less (Edwards,1993). Though this may seem insignificant to a non-responder or a non-chemist, this statement embodies the multitude of hazards faced in response. The fewer the parts, such as the number of elements in a compound, the lighter the overall weight of a substance. Substances with relatively low molecular weights can easily be moved between the physical states of liquid or gas by the use of pressurization and temperature (Compressed Gas Association,1990 pp. 5-6).

NFPA 472, Standard for Professional Competence of Responders to Hazardous Material Incidents (2002), refines a responders understanding of the ability of a substance to move between liquid and vapor states. NFPA standard 472 states an Operations level trained responder to a hazardous material incident shall understand the following terms: vapor pressure, flash point, and boiling point (chap. 5.2.3). Each term directly measures the ability of a liquids volatility, or ability to produce vapors. The volatility is important when put in the context that vapors contain the same hazards as the product producing the vapors. “Since it is the vapor of the liquid, not the liquid itself, that burns, vapor generation becomes the primary factor in determining the fire hazard” (Benedetti,1997,p. 7). To further define the understanding of flammable and combustible liquids volatility, a classification system of Class 1, 2 or 3 has been established with Class 1 defined as a liquid that produces enough vapors to burn at a temperature less than 100 degrees Fahrenheit (Benedetti,1997,p.31).

These principles relate that a)hazards exist in vapors and b)vapors, based on the molecular weight of the substance, can be easily produced. This forms the foundation of why vapor protective clothing standards and flammable liquid standards are necessary. In short, the intent is to protect personnel against the perceived hazard of the vapor.

Intent of current Standards

Standards set a minimum performance criteria for fire fighter safety. Standard test measures ensure all manufacturers evaluate their products in a similar manner and represent them accordingly (Stull,2002,p. 61). As mentioned earlier, the standards for CPC as set forth by the NFPA are more performance based as opposed to rigidly component based. NFPA 1991,Standard on Vapor-Protective Ensembles for Hazardous Materials Emergencies (2000), the accepted standard for the fire service in dealing with vapor protective clothing, requires a vapor protective ensemble to not be labeled as certified to NFPA standard 1991 unless it “meets or exceeds all applicable requirements specified in this standard”(chap. 2-1).

Manufacturers of vapor protective ensembles can meet the requirements set forth by NFPA standard 1991 by utilizing either of two suits: a “disposable” plastic suit usually requiring an overcover, or a reusable “single-skin suit” usually made of rubber (Bauer,2001,p.50).

It is appropriate at this time to state several of the requirements necessary for NFPA standard 1991 compliance. It should also be noted NFPA 1991 has several optional performance requirements. Optional requirements are totally at the discretion of the manufacturer of the CPC ensemble and are not necessary to have a garment labeled NFPA 1991 compliant.

1) Resistance to flame impingement- Required for compliance. The definition for this test states the material shall not ignite during a three second exposure to open flame, or if ignition occurs shall not burn a distance greater than four inches, shall not sustain a burn on the material for more than 10 seconds, and shall not drip and flow. (2000,chap. 5-2.2;American Society Testing Materials,2000,ASTM F 1358,section 4).

2)As a note to the above, should a suit fail the flame impingement test, “any combination or… multipiece element needed to meet any… performance requirement shall also meet all requirements”(2000,chap. 2-3.14). An overcover can be used as an outer layer to meet flame impingement criteria as well as other physical performance criteria including physical strength and durability. This outer cover is usually aluminized.

3)Chemical flash fire test- This test is optional and not required for compliance to NFPA 1991 (2000,chap. 5-6). A chemical flash fire is defined as a flammable or ignitable flame front. “This flame front, a fireball, will release both thermal and kinetic energy to the environment” (2000,chap. 1-

3.14). This performance standard can only be tested in a controlled chamber (2000,figure 6-27.4.4).

4)Permeation test- Required for compliance to NFPA 1991. The suit material is tested against the passage of vapors through the suit material at a molecular level. The testing shall be conducted on 21 listed chemicals (2000,chap. 5-2.1)

Based on the four above listed items, compliance to the performance standards of NFPA standard 1991 are both required and optional. Therefore, if a CPC garment is not labeled as meeting the optional requirements of 1991, the true ability of that garment to meet the optional performance standards remains unknown. An ensemble intended to provide flame resistance, i.e. a plastic suit with overcover, cannot and should not be expected to provide chemical flash fire resistance, unless so labeled.

Risk analysis

An Incident Commander shall be responsible for the overall incident safety of members involved at scenes and shall integrate risk management into the regular functions of incident command (NFPA 1500,1997). An effective command conducts a risk assessment based on: situational understanding; the incident commanders training and background; and operational procedures based on accepted practice. Risk management is best described as “a probability that a certain harm can occur”(Lesak,1999,p. 216). To base a risk assessment on the material we have covered to this point, consider the background and training requirements for incident commanders.

Command at a hazmat incident requires training as outlined in NFPA standard 472: Professional Competencies of Responders to Hazardous Materials Incidents. An Incident Commander must have training to Operations level with the added competencies of understanding incident command. Operations level training requires less competencies than that of a Technician level trained member in understanding CPC. The Incident Commander may allow specific risk assessments, beyond his level of knowledge, to be made by “tactical-level management” (NFPA 1500,1997,chap. 6-1.3).

A common distinction occurs with command establishing strategic goals involving a hazardous material branch and a separate fire branch. “Fire control is almost self-explanatory. The IC must identify methods to minimize the potential impact of a fire, whether it is currently working or a realistic threat” (National Fire Service Incident Management System Consortium,2000,p.88). In essence, fire and the hazardous material become seemingly separate and distinct entities at an incident.

In summation, the above listed areas of physical properties of vapors, NFPA requirements for vapor protective clothing, and risk assessment necessary for properly utilizing CPC would indicate a cohesiveness that should permeate decision making. There are, however, several areas of interest that have contributed to existing standards and accepted practice that deserve further consideration.

NFPA standard 1991 lists 21 chemicals used in testing of suit materials for the purpose of permeation (2000,chap.5-2.1). This testing is the same list as promulgated by American Standards Testing Method F 1001 (1999,Section 6). These specific chemicals represent the classes of common chemicals encountered during hazardous material emergencies (NFPA 1500,1997,appendix A-5-6.1). Upon closer investigation of the 21 listed chemicals that are representative of hazardous material incidents, many contain flammable or combustible properties.

Table 1

Flammable/Combustible Chemicals Listed as Percentage of 21 Test Chemicals for Compliance to NFPA 1991(2000)

Chemical Physical State/Properties	Number	Percentage of Test Group
Flammable Liquids- Class I	11	52%
Flammable Gases	1	4%
Combustible Liquids	2	9%

The properties of chemicals in Table 1 are a comparison of the list of chemicals used for permeation testing for compliance to NFPA 1991 (2000) to the individual chemicals properties as listed in the National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards, 1997 edition. NIOSH is a respected organization “that develops and periodically revises recommended exposure limits for hazardous substances or conditions in the workplace” (Department of Health and Human Services,1997,p. viii).

Expanding the concept of chemicals with dual properties of toxic and thermal properties, the NIOSH Pocket Guide was reviewed not in its entirety, but pages 1 through 117. Any solid chemical listed on pages 1-117 was not included in this review. Solids are not a vapor hazard and not inclusive to this research paper. The review is based on 90 liquids and 15 Gases.

Table 2

Percentage of Liquids and Gases Found in NIOSH Handbook (1997) from Pages 1-117 With Toxic and Flammable/Combustible Properties

Chemical Physical State/Properties	Number	Percentage of Total Group
Flammable Liquids-Class I	43	47%
Flammable Gases	7	47%
Combustible Liquids	46	51%

Based on Table 1 and Table 2, the concept of encountering an incident with the dual hazard of flammability and toxicity is a real possibility. Of the liquids listed in Table 2, 89 of 90 listed chemicals have flammable and/or combustible properties.

Based on arguments that toxicity is reached at relatively low atmospheric content, as compared to higher ranges necessary for flammable properties to be achieved (Cholin,1997), consider that ammonia is considered non-flammable. Based on the Department of Transportation requirements, ammonia does not meet the characteristics of a flammable gas(Keegen,1999.p.439). In Shreveport, Louisiana, an ammonia leak ignited killing a hazardous material team member and injuring another. Based on a given risk assessment, even a non-flammable gas can be considered a dual hazard chemical.

A stunning statistic is of 40,000 Level A suits sold, only 1500 outer garments were sold. This indicates a majority of Level A users are non-NFPA standard 1991 compliant (Bauer,2000,p. 50). The common theme behind this is many end users wish to only have chemical protection, i.e. they do not anticipate encountering dual hazard chemicals in amounts sufficient to warrant the cost of purchasing the additional overgarment for flame resistance and other physical features of the suit (Stull,1996). This fact alone, coupled with the risk assessment required of both the fire service and occupational guidelines of industry (Keegen,1999) indicates a glaring weakness in the realization of the true hazard potential of incidents.

It is not unusual to encounter a mindset that an overgarment is used exclusively for protection from the flammable hazard of materials. This stems from slang statements made by numerous parties calling overgarments “flash suits”. “While responding to an ammonia leak at a refrigeration plant… firefighters chose not to wear their optional ‘flash covers’ that were provided”(Bauer,2001,p. 48). The author later refers to the overgarments as “aluminized overcovers”. This terminology of flash covers and/or flash suits has permeated the fire service. Members of my division have associated “flash suit” to mean donning the garment will offer flash protection. However, chemical flash protection is an option, not a requirement of NFPA 1991.

Summation

The significance of this research paper, as previously stated, is local jurisdictions model accepted practice as defined by national standards. Per the background criteria provided, the significance of having a chemical flash protective garment available to responders is warranted. In a risk assessment, an Incident Commander and/or a tactical-level manager should recognize the case for a chemical flash protective garment and take such steps to insure the safety of personnel in a potential dual event, of which it has been established, can exist (NFPA 472,2002,section 10.2 (D)).

Background information was sought to establish the manufacturers currently offering NFPA 1991 compliant suits with optional chemical flash fire protection. Currently no manufacturer offers such a product, per the Safety Equipment Institute (2003).

Based on NFPA standard 1991 indicating optional performance standards including flash protection are warranted and in the absence of such protection, the Cleveland Fire Department has sought to investigate a means to achieve safety at dual events by following the appendix to NFPA standard 1500 and creating performance based ensembles for thermal protection at chemical events. This research will benefit the Cleveland Fire Division by shifting the paradigm from complacency in operating procedures to establishing more realistic expectations of personnel performance and safety. This adheres to the course concepts of simultaneous personal development as well as team development. This research will promote the objectives of the United States Fire Administration in making departments more aware of potential harm to fire fighters, and promote risk reduction amongst private sector concerns using the same CPC.

Literature Review

For the literature review, resources were obtained to assist in defining the parameters of a thermal event in a chemical flash fire, and how that event could have a negative impact on personnel in existing Vapor Tight ensembles used by the Cleveland Fire Department. Authors and publications were researched who support the use of personal protective equipment (PPE) to meet the challenge of the situation when a clear scope of use of PPE is not defined by current standards. Sources were obtained from the National Fire Academy's Learning Resource Center, Cleveland Public Library City Hall branch, available references from the Cleveland Division of Fire and personal contact with knowledgeable person(s) in the field of CPC including manufacturers and NFPA Technical Committee members.

CPC in thermal environments

Dupont materials are used in the construction of vapor protective suits utilized by the Cleveland Fire Department. Based on information from Dupont, polyethylene is the major component of disposable suits meeting NFPA 1991 certification (J.P. Zeigler,personal communication, January 24, 2003). Polyethylene, in the simplest terms, is the highest volume plastic in the world. To understand the burning characteristics of polyethylene, the building blocks of what makes this plastic is important to understand (Fire,1991,p. 128).

Polyethylene comes from a monomer called ethylene. The term monomer means one, or one part of. As the monomer splits and bonds with other monomers, the process is called polymerization. Poly means many parts. Therefore, the polymer known as polyethylene is actually produced from the monomer ethylene (Manahan,1993,p. 331). Polymers, upon being exposed to heat, will begin a decomposition to the same materials as the monomer would decompose to. The difference being a polymer, or plastic, has greater density. Therefore, if the monomer is flammable, the polymer will decompose to the same flammable substance, but with greater volumes of combustion byproducts due to the density of the plastic (Edwards & Edwards,1994). Ethylene, the basis or monomer for the suit material used in many disposable CPC suits, is a substance made of only 2 elements, carbon and hydrogen. Ethylene is rated flammable as per the qualifications of NFPA standard 30 (Benedetti,1997,Table A-1-7.3).

Polyethylene is placed in a group of plastics known as thermoplastics. “Thermoplastic articles tend to melt and flow when heated”. The author further states this decomposition can produce flaming and tar-like dripping, “which is difficult to extinguish and may start secondary fires”(Cohn,1997,section 4-125). This concept is taken a step further by Fire (1991) when he states that polymers containing only carbon and hydrogen “burn hotter… since the polymer chain is all fuel” (p.128). As a measurement of the ability of polyethylene to produce heat of combustion, one pound of polyethylene will produce 20,000 British Thermal Units (BTU) of energy. This is the second highest amount of thermal energy released by common plastics (Table 6.1).

The question arises why would a polymer such as polyethylene be used in CPC when the material is based on (a) a flammable liquid, (b) can produce several types of fires (solid and flowing liquid), and (c) has a high heat and fire by-product output? The answer is that the material has good moldability; is relatively light; and is highly chemical resistance, thus its’ mulitiple use designations (Cohn,1997).

With a basic understanding of suit material, the second question is to determine if it is realistic to assume polyethylene will ignite if exposed to a chemical flash fire? NFPA standard 1991 states;

> A chemical flash fire requires an ignition source and a chemical atmosphere that contains a concentration above the lower explosive limit of the chemical. Chemical flash fires generate heat from 540 degrees Celsius to 1040 degrees Celsius (1000 degrees Fahrenheit to 1900 degrees Fahrenheit). As a rule, a structural flash fire is confined to a designated area with walls as a boundary. A chemical flash fire depends on the size of the gas or vapor cloud and when ignited, the flame front expands outward in the form of a fireball (2000,Appendix A-1-3.14).

The concept of mixing vapors (fuel) and air has significant research. The reaction of combustion can occur in a fuel-air mixture “at a velocity faster than the speed of sound” (Cruice,1997,section 1-74). The fire front created can extend “approximately ten times the initial volume of the mixture” (Cruice,1997,section 1-74). The pure destructiveness of fuel-air mixtures has also been included in books and manuals dedicated to explosives. The common propane tank found in numerous industries and residential settings can be burst, by a charge attached to the tank, and “approximately 125 milliseconds later, the main charge can detonate the cloud (fuel-air mixture)” (Harber,1990,p. 35). The use of fuel-air mixture bombs, though not considered traditional, have been used in deliberate attacks such as the Beirut bombings of Marine barracks in 1983 and again at Columbine High School in 1999 (U.S. Fire Administration,n.d.). As an example of the comparisons of various fuel-mixtures, first consider ammonia. Ammonia ignited in Shreveport burning a fire fighter in CPC. The fire fighter died with 3rd degree burns over 90% of his body(Peterson,n.d.). Ammonia has a heat output measured in BTU per pound of approximately 500 (Compressed Gas Association,1990,p. 234). Propane, a recognized fuel gas and a potential secondary device, has a BTU of 21,548 per pound (Amerigas,1995).

When a fuel-air mixture occurs, it is important to note if the location is confined or unconfined. These terms can have several meanings to bomb technicians. Our intent is to explain if the reaction is occurring in a pipe or confined space or in an open area. Consider a reaction in a pipe, “where the length exceeds the diameter by a factor of ten or more” detonation can occur, or the reaction is faster than the speed of sound (Cruice,1997,section 1-74).

Polyethylene has a relatively low ignition temperature of approximately 660 degrees Fahrenheit. Perhaps more importantly, the material will begin to melt between 224 to 284 degrees ÿhem.ÿheit (Fire,1991). A flame impingement test is a 3 second exposure of a specimen (sample of material) to a gas flame (NFPA 1991,2000; ASTM F 1358,2000,section 4.1). Polyethylene, therefore, will melt and flow and ignite when exposed ‘to any common ignition source, so long as the ignition source is held in place…”(Fire,1991,p. 141).

Current Use of PPE in Dual Events

The use of CPC is based on functional performance, such as fit, and the performance requirements of the garment. Several authors have understood the associated importance of matching protective gear to the function of the task when at a dual event. This message is stated in NFPA standard 1500 that CPC “should be selected by evaluating its performance characteristics against the requirements and limitations imposed by the response activity” (1997,Appendix A-5-6).

NFPA standard 1971, Protective Ensemble for Structural Firefighting, has performance requirements specific to heat transfer capabilities. This is accomplished through specific layering techniques of material(2000,chap. 4-1). Also, NFPA 1971 certification does not extend to use in hazardous materials environments due to the non-performance requirements of hardware items and permeation concerns of the garment if they came in contact with chemical vapors(Appendix A-5-6).

Lesak (1999) writes that dual zones should be considered for dual events. By creating a sub-zone in the area where activities are occurring, personnel dressed in CPC can perform leak control and personnel in structural gear can perform fire suppression duties. Personnel must understand their roles and their PPE limitations to operate safely in this situation.

J. Stull writes responders must recognize the difference in risk when dealing with "a gallon of toluene versus a tank car of the same chemical"(1996,p. 24) The same author prepared a report under a United States Fire Administration grant comparing different CPC ensembles (available at the time of the report) against chemical flashover situations (Stull,Vighte,Mann,Storment,1992). The tests were conducted against swatches of materials and in several cases, with entire ensembles. The ensemble tests were conducted in a chamber somewhat similar to the current requirements of NFPA standard 1991 performance testing for chemical flash fire requirements. Several ensembles showed some integrity to chemical flash fire, but had multiple areas that results could not be completely discerned.

These tests were conducted using a measured heat flux of 2.0 calorie/sq. cm./s at a sustained 6 second interval. This was an approximated heat flux based on a chemical flash fire. The amount of heat flux, or energy, permeating the garment was attempted to be measured to determine if skin burns would be received by personnel in the garment. Results showed a single garment allowed more energy to pass to the wearer as opposed to an ensemble with an overcover.

The Society of Fire Protection Engineers (2000) and the American Society of Testing and Materials (F 1930,2000) support the concept of measuring a constant heat flux against a material or ensemble with a manikin inside the garment. The manikin, through thermal sensors placed on the outer surface (representing the skin layer of humans),would measure the amount of heat flux transferred through the garment. This measurement of heat flux could be correlated to approximate degree of burn, both in specific areas of the body and total body burn.

The concept of heat flux was researched in a previous Executive Leadership research project (Jarboe,1997). This research concluded the use of various dry undergarments, when worn under NFPA standard 1971 compliant structural fire fighting ensembles, increased the total protection time of fire fighters from thermal burns when exposed to a constant of 2 calories/sq.cm./s. The tests supporting the hypothesis of the report were conducted with Dupont in controlled conditions.

Research supporting combining accepted standards, such as NFPA standard 1971 and NFPA standard 1991, to achieve thermal and chemical protection against chemical flash fire could not be found.

Exhaustive research could not produce a viable answer to the research questions. Therefore, with an understanding of the attempts made by the Cleveland Fire Department in the past to create ensembles for protection against chemical flash fires, a joint testing session was established with Dupont Personal Protection, Spruance Plant, Richmond,VA. With the cooperation of Dupont and Lakeland Industries, ensembles were tested in a controlled thermal environment to develop answers to the research questions.

Procedures

Materials used

The materials used were obtained from the Cleveland Fire Department, Lakeland Industries and Dupont Chemical. Materials used in testing were items used or items duplicated for use by the Cleveland Fire Division.

Turnout gear was used. All turnouts had been recently washed. Turnouts met the following specifications;

1- Outer shell- Nomex® III aramid- 7.5 oz./sq. yd.

2- Thermal liner- 60% Kevlar®/ 40% wool

3- Moisture barrier- Crosstech®

4- NFPA 1971 compliant, 1997 edition

Lakeland Chemical and Dupont contributed CPC as follows:

1- Lakeland Tychem® Level A Suits

2- Aluminized overcovers

Various other garments used included:

1- Nomex® coveralls- 6.0 oz./sq.yd.

2- Nomex® hood

Thermo-man® background

Duponts thermo-man® is an instrumented thermal manikin system that measures the thermal protection of whole garments during a controlled flash fire simulation. The conditions the manikin and garments are exposed to are reproducible.

The manikin is 6 feet, 1 inch tall with 122 heat sensors distributed across the body and head. Twelve propane torches, simulating flash fire conditions, engulf the manikin in a fireball for a measured time frame.

Data from the thermal sensors is collected at half-second intervals during the flame exposure and 30-90 seconds thereafter to allow complete penetration of heat through the ensemble. A skin model is used to calculate amount, degree and location of second and third degree burns based on estimates of human tissue tolerance to the heat and the calculated heat flux at the surface of the sensors (R.H. Young, personal communication, January 24, 2003).

Test parameters

The thermo-man® manikin is exposed to a known heat flux and calibrated for accuracy. To simulate chemical flash fire conditions, the propane system is then computer controlled for heat flux and time. To simulate a chemical flash fire, a constant heat flux is needed of 2.0 calories/sq.cm./s(NFPA 2112-2001,table B-1). Total exposure time exposed to the flame front varied between 3-5 seconds, producing total heat fluxes of 6-10 calories/sq.cm./s(R.H. Young). All tests were to be monitored for 90 seconds to record complete thermal transfers and observational results.

Acquired data from the sensors generates a total body burn pattern report and relates the data to location of second and third degree burns.

All tests were filmed from the front view of the suit for later observational review.

Test Limitations

The tests did not adhere to the strict performance guidelines as outlined in NFPA 1991 for flash protection. The tests, as conducted, relied on generated data from thermo-man® sensors for body burn, and observational data. Observational data is limited based on the knowledge and experience of the person viewing the results. The video of the tests is included as observational data (Appendix A). The video supports the observational data and must remain with this report as a recognized portion of the content and is available only for training purposes.

Several specific areas of limitations are noted:

1- The chamber for flash testing CPC, as described in NFPA 1991, must have propane flow into the chamber and then be ignited. The thermo-man® chamber ignites prior to a vapor cloud being formed. The propane torches are ignited immediately upon release of product.

2- Ensembles tested were not all NFPA 1991 compliant nor were multiple tests done on exactly the same ensembles to establish average performance criteria. Tests conducted were without several ensemble pieces, including chemical gloves, helmets and SCBA. This was due in part to cost of the testing.

3- Hands and feet are exempt from 100% body burn measurements (ASTM F1930). Therefore, thermo-man® has no burn measurements in these extremities.

4- Thermo-man® is held upright in the testing chamber by a support adhered to the back of the neck of the manikin. This support required the CPC be cut to fit on the manikin. The area of the cut was taped prior to testing.

5- All testing was done with CPC uninflated. Personnel could encounter potential chemical flash situations with suits inflated and a trapped insulation layer of air.

6- Thermo-man® required a protective layer of material between the sensors and the drip and flow characteristics of the plastic CPC. Therefore, nomex® coveralls were utilized on several tests when this may not have represented an ensemble actually used by the Cleveland Fire Department. A more utilized layer of material against the skin of personnel is cotton shirts and/or work uniforms.

7- In all tests conducted, nomex® hoods were used. These are not normally utilized in CPC ensembles. The hoods were used, again, to protect thermo-man® from drip and flow characteristics of the garment. Thermo-man® is not designed to measure the melt/drip hazard of a burning polymer.

Results

Test 1- Total heat flux- 6 calories

Ensemble tested- Tychem® TK Level A over turnout gear

Results- 2% second degree burns, 1% third degree burn, 3% total burn injury. Garment melted and flowed. The vapor protective integrity of the suit was destroyed. The burning suit material was clinging to the turnout gear in the chest and leg area. The fire was growing slightly in integrity through the 90 second acquisition period. Trauma was in the head area and lower left leg (Appendix B).

Test 2- Total heat flux- 10 calories

Ensemble tested- Tychem® TK Level A over turnout gear

Results- 2% third degree burn, 2% total burn injury. The garment was destroyed by the added heat flux in comparison to Test 1. Pool fires were more evident as was burning residue material on the undergarment. When the exhaust fans were turned on in the chamber and air began to circulate in the chamber, the burning characteristics of the garment material greatly increased. Major burn trauma was to the head area (Appendix C).

Test 3- Total heat flux- 10 calories

Ensemble tested- Tychem® TK Level A over turnout gear. Also utilized aluminized overcover.

Results- 1% second degree burn, 2% third degree burn, 3% total burn injury. The Level A suit caught fire directly interior to a relief valve situated on the aluminized overcover. This would imply the heat entered through the valve. Flame was visible through the visor and was predominant in the head area. Major trauma was to the head area (Appendix D).

Test 4- Total heat flux- 10 calories

Ensemble tested- Tychem® TK Level A with aluminized overcover, nomex coverall under Level A

Results- 6% second degree burn, 11% third degree burn, 17% total body burn. The Level A garment ignited near the right lower arm. The visor of the outer garment appeared to pressurize and vent, creating a void and a chimney effect was created. The results showed a majority of trauma to the right arm, back, and head. The fire was difficult to extinguish as the overgarment, while mostly intact, trapped the heat of combustion(Appendix E).

Test 5- Total heat flux- 10 calories

Ensemble tested- Tychem® TK Level A over nomex coverall.

Results- This test was terminated at 30 seconds. 5% second degree burns, 6% third degree burns, 11% total body burn. As in previous tests with no overcover, the Level A suit material was destroyed and residual and pool fires developed. As a concern to potential damage to thermo-man sensors, the test was terminated at 30 seconds. Trauma was recorded in the arms and head area (Appendix F).

Test 6- Total heat flux- 10 calories

Ensemble tested- Tychem® TK Level A over turnout gear

Results- 2% third degree burns, 2% total body burns, As in the other tests with no overgarments, the Level A suit was destroyed with several clinging fires on the garment and pool fires developing. Most trauma was to the head area (Appendix G).

Research questions/results

RQ1: In simulated flash fire conditions, what ensembles perform best against flame impingement based on predicted degree of burns and total body burns to the wearer?

Based on body burns in the second degree, third degree and total body burns, all tests conducted with the ensemble consisting of structural fire fighting coat and bunker pants being worn regardless of the overcover (Level A garment with or without aluminized overcover) were the most protective of personnel. Tests utilizing turnout gear showed 2%- 3% total body burns. Tests conducted without turnout gear as an underlayer showed total burns of 11% and 17%.

RQ2: What hazards, other than flash fire burns, can affect personnel wearing various CPC ensembles in thermal events?

A consistent result of the testing showed head trama from burns. Heat and by-products of combustion consistently were trapped in the visor area of the garment. The drip and flow characteristics of the plastic garment contributed to solid and liquid fires in the immediate area of the testing and on the manikin. The vapor protective characteristics of the garment were compromised in all tests.

RQ3: Do the results of this testing suggest subjective analysis (both from generated reports and visible testing results) be applied to fireground tactics with potential for dual events, i.e. chemical and thermal?

The results support subjective analysis should be applied to fireground tactics, risk analysis and dual event potential for fire fighter safety.

Discussion/Implications

The results of this research paper must be taken into account with the background material and literature review. Per this research paper, a basic understanding of several factors specific to personnel safety may be unclear to users of CPC.

The tests conducted in cooperation with Dupont show the importance of protection from thermal events while carrying out tactics in vapor proective garments. The head area appeared to be the main focal point of heat injury. Further results, based on thermo-man testing, show a high probability of burn injury without the overgarment or turn out gear as an undergarment. Testing the combination of a flame resistant overgarment used in conjunction with Level A still left doubts as to the ultimate condition of the wearer. Subjective observation suggests the overgarment may contribute to holding combustion byproducts and inhibit flame extinguishment. In a true flash fire test, that being the introduction of vapor clouds of propane prior to ignition, the concept of entrapment may imply the entrapment of ignitable vapors within the ensemble. Upon ignition, any combination of events may occur.

In a completely generic sense, the testing shows that a substantial fuel load is added to personnel when donning Level A disposable suits. In the same sense, the fuel load has the potential to remain on personnel in a drip and flow physical state. This physical state contributes to overall burns long past the time of the actual flash fire (Appendices B-G). Another concern of the drip and flow characteristics is the pool fire effect around personnel. If personnel become disoriented, which may happen as a result of head trauma from burns or byproducts of combustion, it is not out of the ordinary to expect them to fall and or crawl from the area. This position may contribute to dripping material forming a pool fire the members are crawling through. Also, the concept of Level A ensembles require the suit to be inside the boots, not vice-versa. Therefore, dripping and flowing could create pool fires inside ensemble parts, such as boots and gloves. The lack of required thermo-man data for hands and feet make this speculative.

This research defined the threat of total body burns to the wearer can be reduced based on ensembles worn. The research also has shown a risk is involved in donning any Level A garment where the risk of a thermal event is also present. Without an overcover, a disposable Level A suit is suspect to pass any flame resistant requirements. These concepts have to be weighed heavily into risk analysis.

The amount of heat flux generated in testing an ensemble for performance characteristics is paramount. Observation of the tests show an increased heat flux may contribute to the drip and flow characteristics of the material(s) involved, secondary harm to the wearer, and confusion to escape the area.

Recommendations

Recommendations based on this research are as follows:

1- Technical committees should stress training competencies outlining differences in flash protection versus flame resistance. Garment labels, whether for overgarments or vapor protective suits, should specifically note the required performance standards and if those requirements are met. An example competency would state: Personnel shall, given an example label, recognize the difference in label information.

2- The term ‘flash suit’ should no longer be used in articles or in manufacturers presentations.

3- Training requirements should reflect risk analysis for dual events, i.e. thermal and chemical. This training should stress the concept of intervention to assist personnel if a chemical flash occurs. Training should reflect that personnel may become disoriented and unable to leave the area. Pool fires may cause further burns to members beyond the flash itself. This intervention should be for personnel other than a back-up team dressed in CPC. Intervention will be in appropriate PPE, possibly structural fire fighting ensembles.

4- To further define the importance of safety and the confusion of multiple garment ensembles, manufacturers and technical committees should strive for a clearer distinction between non-compliant single skin garments and single skin or multiple layer garments that fully meet the NFPA 1991 standard for chemical response, i.e. containing all necessary physical performance criteria.

5- Technical committees are recommended to consider that the extent of a fire front from a chemical flash fire may be hard to predict. Therefore caution should be used in relying on instrumentation to define the extent of harm, including the wearing of CPC into confined spaces.

References

American Society for Testing and Materials.(1999). *Standard guide for selection of chemicals to evaluate protective clothing*(ASTM F 1001,p.1-17). West Conshohocken,PA:American Society for Testing and Materials.

American Society for Testing and Materials.(2000). *Standard test method for evaluation of flame resistant clothing for protection against flash fire simulations using an instrumented manikin*(ASTM F 1930).West Conshohocken,PA: American Society for Testing and Materials.

American Society for Testing and Materials.(2000). *Standard test method for effects of flame impingement on materials used in protective clothing not designed primarily for flame resistance*(ASTM F 1358). West Conshohocken,PA:American Society for Testing and Materials.

Amerigas Propane,L.P.(1995,March).*Propane fast facts*(Available from Amerigas, P.O. Box 965,Valley Forge,PA 19482).

Bauer,R.(2000,August). Well suited for hazmats. *Occupational Health and Safety,70*,48-52.

Benedetti,R.P.(1997). *Flammable and combustible liquid codes handbook*(6th ed.). Quincy,MA:National Fire Protection Association

Cholin,J.M.(1997). Gas and vapor detection systems and monitors. In A.E. Cote(Ed.),*Fire protection handbook*(18th ed.)(section 5/chapter 8).Quincy,MA:National Fire Protection Association.

Cohn,B.M.(1997).Plastics and rubber. In A.E. Cote(Ed.),*Fire protection handbook*(18th ed.)(section 4/chapter 10).Quincy,MA:National Fire Protection Association.

Compressed Gas Association,Inc.(1990). *Handbook of compressed gases*(3rd ed.). New York:Van Nostrand Reinhold.

Cook,J.L.(1998). *Standard operating procedures and guidelines*. Saddlebrook,NJ:Penwell.

Cruice,W.J.(1997).Explosions.In A.E. Cote(Ed.),*Fire protection handbook*(18th ed.)(section 1/chapter 6).Quincy,MA:National Fire Protection Association.

Department of Health and Human Services.(1997). *NIOSH pocket guide to chemical hazards*(publication no. 97-140). Washington,DC:U.S. Government Printing Office

Dittmar,M.J.(1998,March). Terrorism:The latest response challenge. *Fire Engineering,151*,66-95.

Edwards,R.(Producer).(1993). *Fire ÿhem. I-HC derivatives*[video series].(Available from SAFE Films,Inc.,3326 Brentwood Drive,S.E.,Grand Rapids,MI 49546).

Edwards,R.,& Edwards,D.(1994). *Fire ÿhem. II*. Grand Rapids,MI:SAFE Films,Inc.

Fire,F.L.(1991). *Combustibility of plastics*.New York:Van Nostrand Reinhold

Harber,D.(1990).Fuel air explosives.*The anarchists arsenal improvised incendiary and explosive techniques*(pp 33-42). Boulder,CO:Paladin Press.

Jarboe,T.L.(1997,December). *Combined thermal protective performance (TPP) of specimen samples of a firefighter’s* *turnour coat,work uniform shirt and tee shirt.*Executive Fire Officer Research Paper.Emmitsburg,MD:National Fire Academy

Keegen,R.J.(1999).*1999-2000 Hazardous materials, substances and wastes compliance guide.*243 West Main Street;Hazardous Materials Publishing Co.,Inc.

Lesak,D.M.(1999). *Hazardous materials:Strategies and tactics.* Upper Saddle River,NJ:Brady.

Manahan,S.E.(1993). *Fundamentals of environmental chemistry*.Chelsea, MI:Lewis Publishers.

National Fire Protection Association.(1997). *Fire department occupational safety and health program* (NFPA 1500,Appendix A).Quincy,MA.:National Fire Protection Association.

National Fire Protection Association.(2000). *Protective ensemble for structural fire fighting* (NFPA 1971). Quincy,MA.:National Fire protection Association.

National Fire Protection Association.(2000). *Vapor protective ensembles for hazardous material emergencies.*(NFPA 1991). Quincy,MA.:National Fire Protection Association.

National Fire Protection Association.(2001). *Flame-resistant garments for protection of industrial personnel against flash fire*(NFPA 2112). Quincy,MA.:National Fire Protection Association.

National Fire Protection Association.(2002). *Standard for professional competence of responders to hazardous material incidents*(NFPA 472). Quincy, MA.:National Fire Protection Association.

National Fire Service Incident Management System Consortium Model Procedures Committee.(2000). *Model procedures guide for hazardous materials incidents*(1st ed.).Oklahoma State University:Fire Protection Publications.

Peterson,D.F.(n.d.).*Hazardous materials* safety.Abstarct retrieved March 14,2003,from http://server.firehouse.com/training/hazmat/training/2001/09_safety.html

Safety Equipment Institute.(n.d.).Retrieved March 13,2003,from http.//www.seinet.orgcertifiedproductlist.vaporprotectivesuits.nfpa.1991.

Society of Fire Protection Engineers(2000).*Predicting 1st and 2nd degree skin burns from thermal radiation.*Bethesda,MD:Society of Fire Protection Engineers.

Stull,J.O.(1996,June). State-of-the-art selection of chemical protective suits.*Responder,3*,24-27.

Stull,J.O.(2002,July). Emergency responder clothing.*Fire & Rescue,40*,58-62.

Stull,J.O.,Veghte,J.H.,Mann,P.C.,Storment,S.B.(1992).Developing and selecting test methods for measuring protective clothing performance in chemical flashover situations. In J.R. McBriarty & N.W. Henry (Eds.),*Performance of protective clothing:Fourth volume,ASTM STP 1133.*Philadelphia,American Society for Testing and Materials.

U.S. Fire Administration.(n.d.). *Wanton violence at columbine high school Littleton,Colorado*(report 128),Abstract

retrieved March 12,2003, from
http://www.usfa.fema.gov/applications/publications/tr128.cfm

Appendix A

Appendix A is a VHS tape showing the tests as filmed at Dupont Laboratories, January 24, 2003.

This video is attached separately. Upon specific request from Dupont, this video may not be reproduced as electronic media and must remain as an attachment to this report. This video may be used for purposes of training and instruction only.

Appendix B

Burn Injury Prediction-Test 1

Test 1

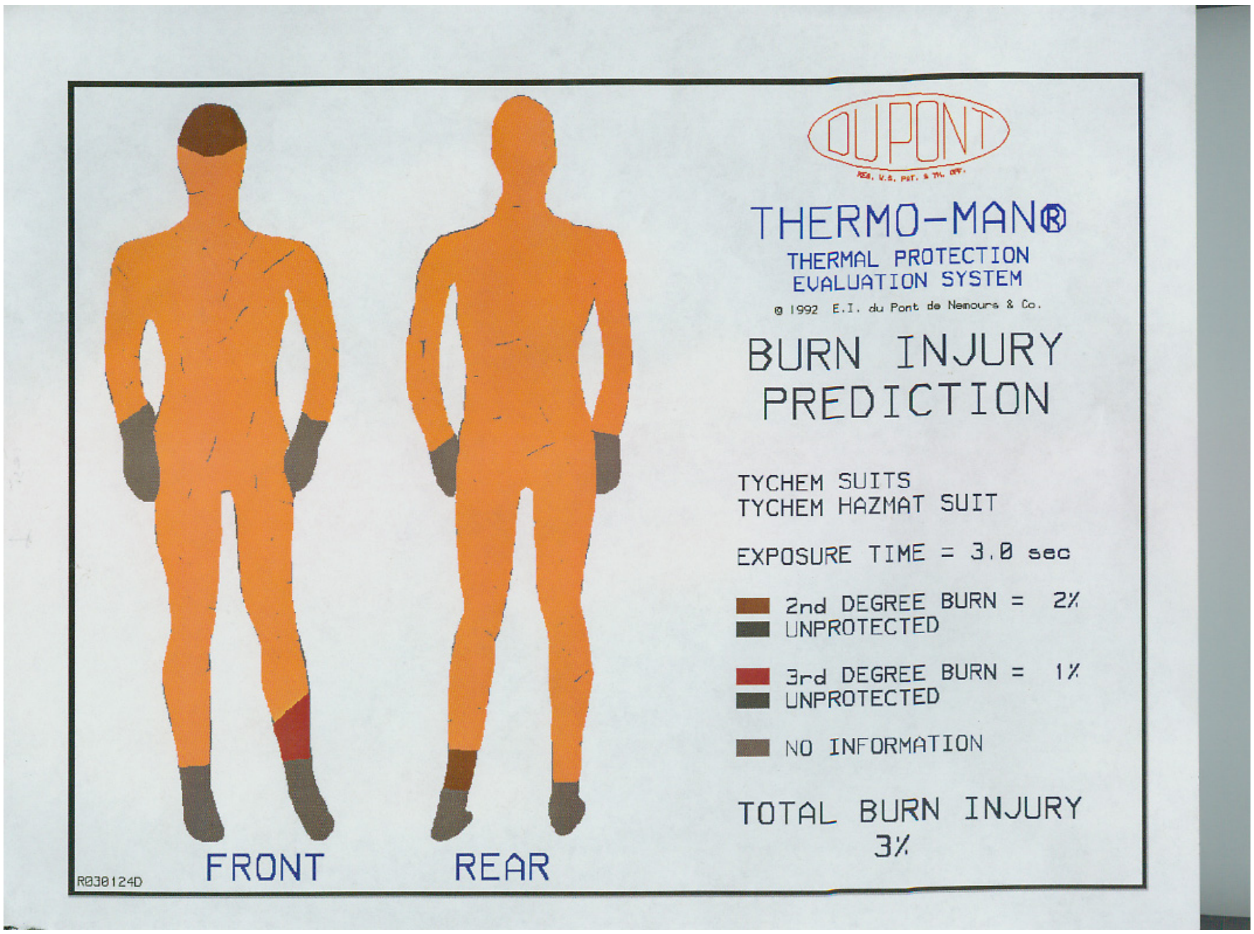

DUPONT
THERMO-MAN®
THERMAL PROTECTION
EVALUATION SYSTEM
© 1992 E.I. du Pont de Nemours & Co.
BURN INJURY
PREDICTION
TYCHEM SUITS
TYCHEM HAZMAT SUIT
EXPOSURE TIME = 3.0 sec
2nd DEGREE BURN = 2%
UNPROTECTED
3rd DEGREE BURN = 1%
UNPROTECTED
NO INFORMATION
TOTAL BURN INJURY
3%
FRONT
REAR
R030124D

Table B1

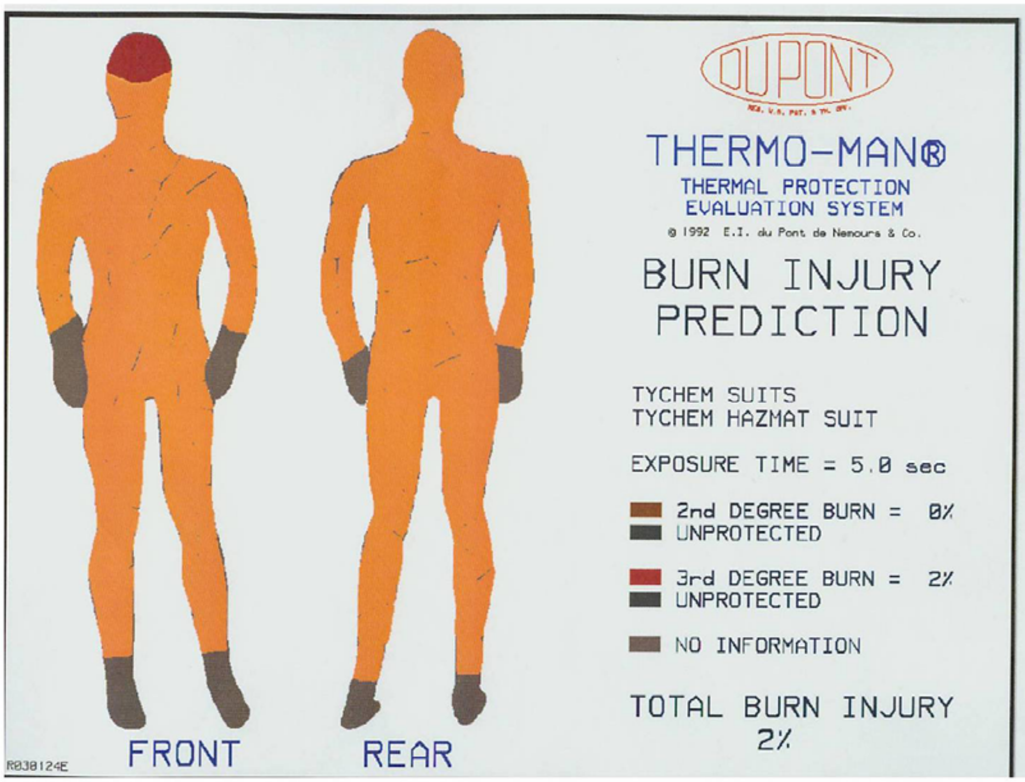
Predicted Time to Burn Injuries

Sensor Name	Total Heat at 2nd Degree Burn Calorie/cm.sq.	Time at 2nd Degree Burn Seconds	Time at 3rd Degree Burn
Head,right eye	1.760	3.6	
Head,left eye	1.733	3.7	
Leg,left lower-front outer	5.707	80.8	85.5
Leg,left bottom rear	4.521	86.4	

Appendix C

Burn Injury Prediction Test 2

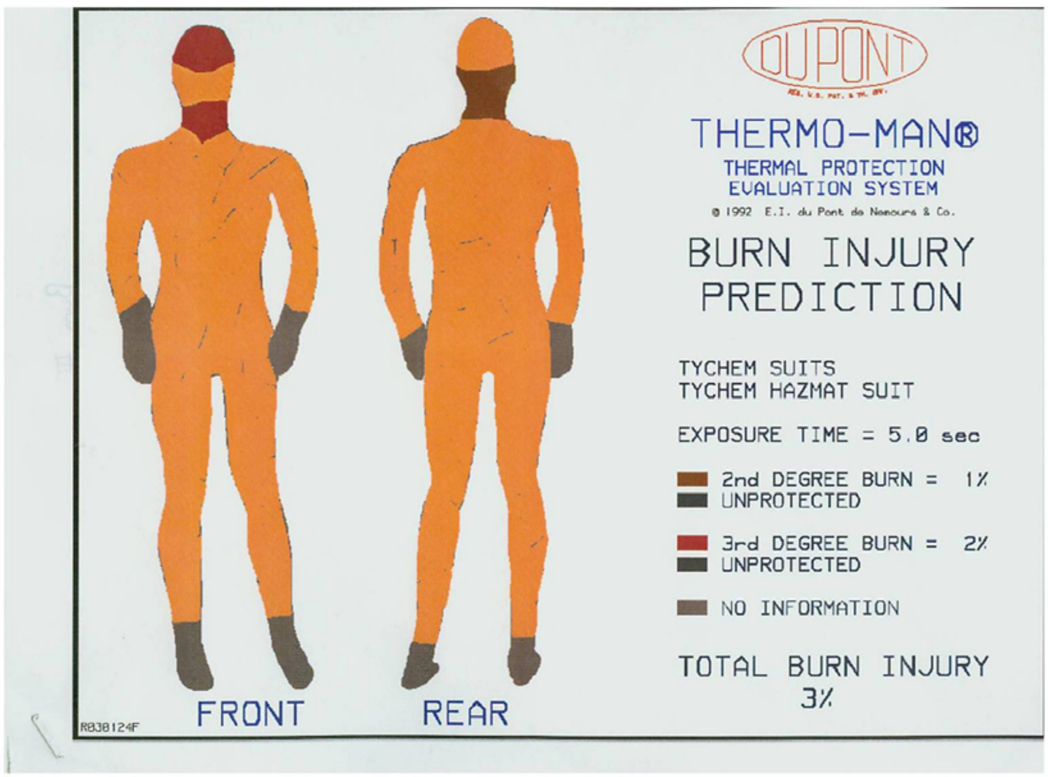
Test 2


DUPONT
THERMO-MAN®
THERMAL PROTECTION
EVALUATION SYSTEM
© 1992 E.I. du Pont de Nemours & Co.
BURN INJURY
PREDICTION
TYCHEM SUITS
TYCHEM HAZMAT SUIT
EXPOSURE TIME = 5.0 sec
2nd DEGREE BURN = 0%
UNPROTECTED
3rd DEGREE BURN = 2%
UNPROTECTED
NO INFORMATION
TOTAL BURN INJURY
2%
FRONT
REAR
R030124E

Appendix D

Burn Injury Prediction Test 3

Test 3



DUPONT
THERMO-MAN®
THERMAL PROTECTION
EVALUATION SYSTEM
© 1992 E.I. du Pont de Nemours & Co.
BURN INJURY
PREDICTION
TYCHEM SUITS
TYCHEM HAZMAT SUIT
EXPOSURE TIME = 5.0 sec
2nd DEGREE BURN = 1%
UNPROTECTED
3rd DEGREE BURN = 2%
UNPROTECTED
NO INFORMATION
TOTAL BURN INJURY
3%
R038124F
FRONT
REAR

Table D1

Predicted Time to Burn Injuries

Sensor Name	Total Heat at 2nd Degree Burn Calorie/cm.sq.	Time at 2nd Degree Burn Seconds	Time at 3rd Degree Burn
Head,right eye	1.661	3.8	9.5
Head,left eye	1.835	3.5	9.0
Head,chin	1.648	4.3	11.5
Head,rear neck	1.708	5.0	

Appendix E

Burn Injury Prediction Test 4

Test 4

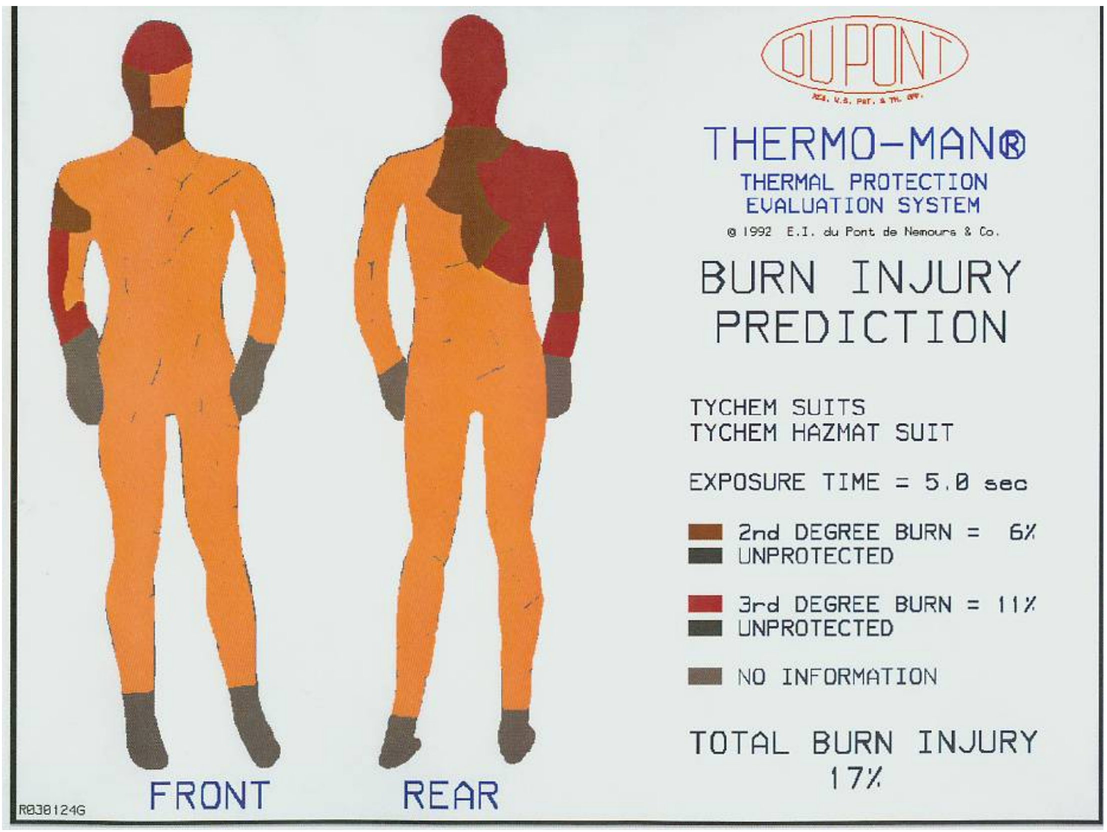

DUPONT
THERMO-MAN®
THERMAL PROTECTION
EVALUATION SYSTEM
© 1992 E.I. du Pont de Nemours & Co.
BURN INJURY
PREDICTION
TYCHEM SUITS
TYCHEM HAZMAT SUIT
EXPOSURE TIME = 5.0 sec
2nd DEGREE BURN = 6%
UNPROTECTED
3rd DEGREE BURN = 11%
UNPROTECTED
NO INFORMATION
TOTAL BURN INJURY
17%
FRONT
REAR
R038124G

Table E1

Predicted Time to Burn Injuries

Sensor Name	Total Heat at 2nd degree Burn Calories/cm.sq.	Time to 2nd Degree Burn Seconds	Time to 3rd Degree Burns Seconds
Head,right eye	1.888	5.9	73.5
Head,left eye	2.203	7.1	77.5
R. lower jaw	5.149	82.5	
R.arm,upper/outer	4.271	83.4	
R.arm,upper/rear	3.877	69.0	75.0
R.arm,mid-outer	3.738	63.9	70.0
R.arm,rear/elbow	4.286	83.0	
R.arm,outer	3.759	66.4	73.5
R.arm,lower/rear	3.856	69.3	74.5
R.arm,lower/front	3.584	54.6	61.0
Head,rear neck	4.442	65.0	73.5
Head,rear upper	4.935	80.0	86.0
Back,lower neck	4.562	86.8	
Back,l.shoulder	4.004	84.4	
Back,r.shoulder	3.901	80.2	88.0
Back,r.shoulder	3.702	73.7	79.5
Back,middle	3.944	86.0	
Back,upper right	3.833	81.5	88.5
Back,upper right	3.996	81.9	89.0

Appendix F

Burn Injury Prediction Test 5

Test 5

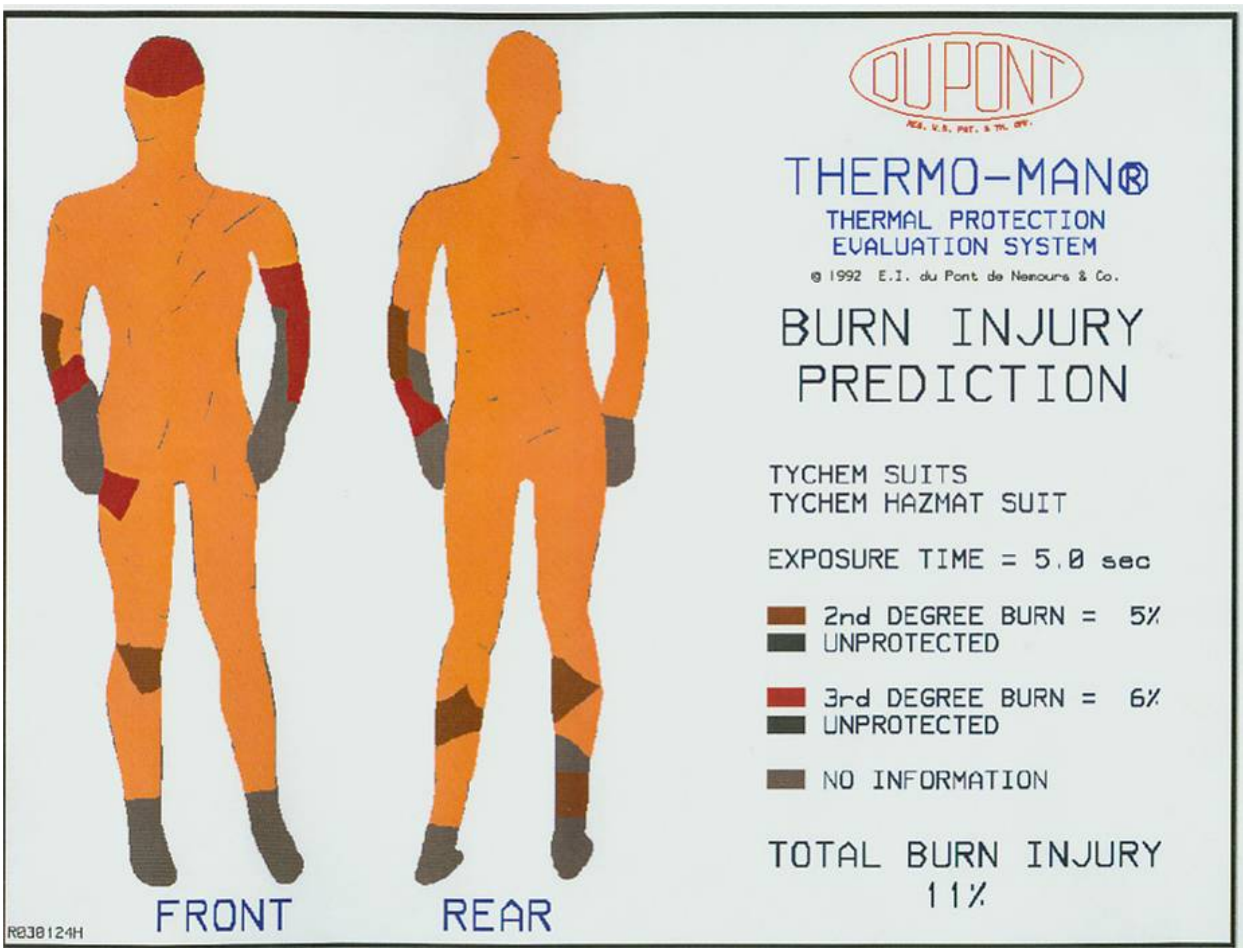

DUPONT
REG. U.S. PAT. & TM. OFF.
THERMO-MAN®
THERMAL PROTECTION
EVALUATION SYSTEM
© 1992 E.I. du Pont de Nemours & Co.
BURN INJURY
PREDICTION
TYCHEM SUITS
TYCHEM HAZMAT SUIT
EXPOSURE TIME = 5.0 sec
2nd DEGREE BURN = 5%
UNPROTECTED
3rd DEGREE BURN = 6%
UNPROTECTED
NO INFORMATION
TOTAL BURN INJURY
11%
R030124H
FRONT
REAR

Table F1

Predicted Time to Burn Injuries

Sensor Name	Total Heat at 2nd Degree Burn Calorie/cm.sq.	Time at 2nd Degree Burn Seconds	Time at 3rd Degree Burn
Arm, left mid-upper outer	2.736	18.9	26.0
Arm, left, elbow	2.057	9.6	
Arm, left, mid-lower front	2.490	14.1	26.5
Arm, left, rear wrist	1.6971	6.2	15.5
Head, right eye	1.856	4.1	8.5
Head, left eye	1.521	3.4	7.5
Arm, right outer	4.019	46.1	
Arm, right lower front	2.936	22.3	28.5
Leg, left calf outer	4.035	36.6	
Leg, right inner knee	3.269	34.1	
Leg, right inner knee	3.394	35.8	
Leg, right bottom rear	3.709	39.8	
Leg, right, thigh upper front	3.178	27.7	33.0

Appendix G

Burn Injury Prediction Test 6

Test 6

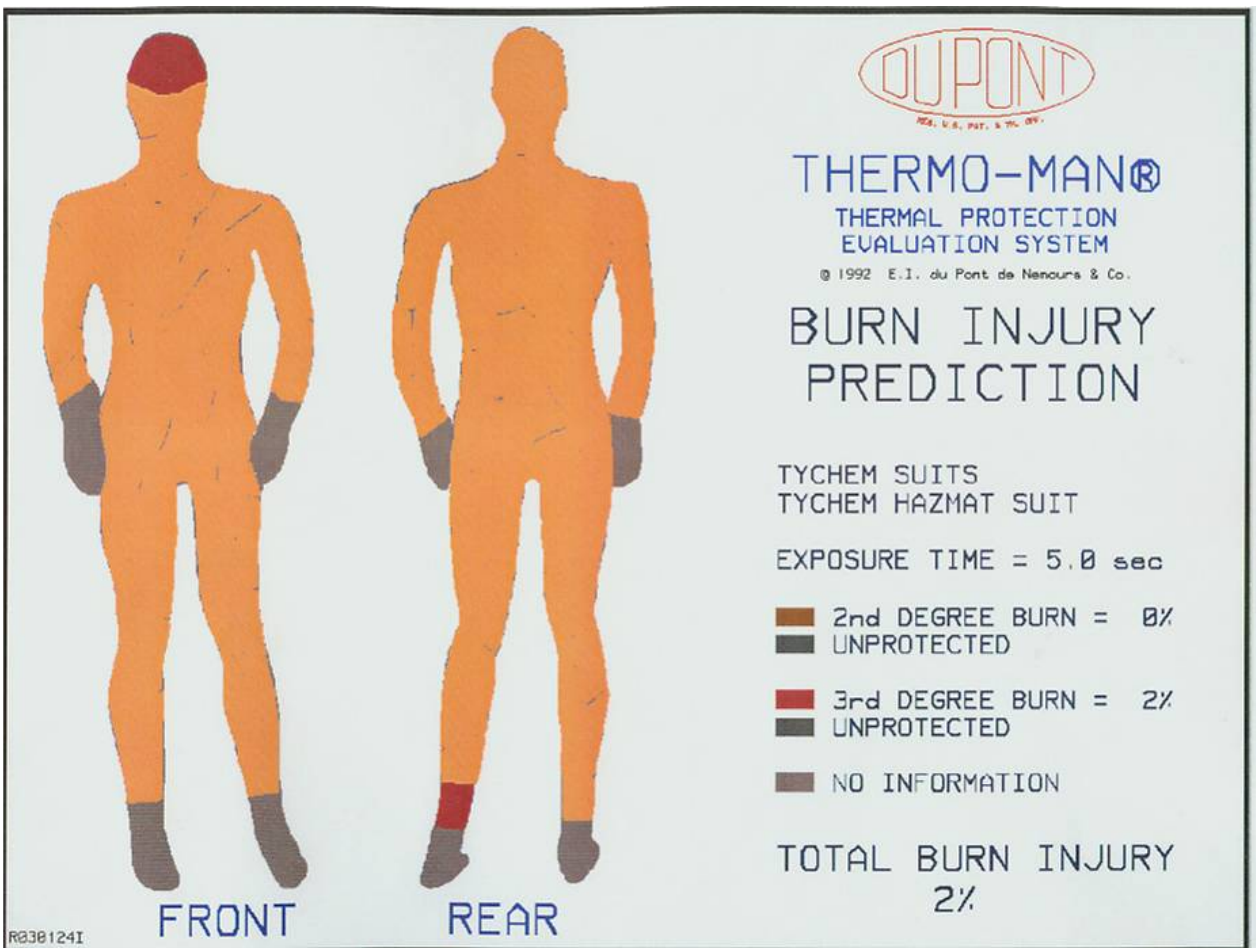

DUPONT
REG. U.S. PAT. & TM. OFF.
THERMO-MAN®
THERMAL PROTECTION
EVALUATION SYSTEM
© 1992 E.I. du Pont de Nemours & Co.
BURN INJURY
PREDICTION
TYCHEM SUITS
TYCHEM HAZMAT SUIT
EXPOSURE TIME = 5.0 sec
2nd DEGREE BURN = 0%
UNPROTECTED
3rd DEGREE BURN = 2%
UNPROTECTED
NO INFORMATION
TOTAL BURN INJURY
2%
FRONT
REAR
R0301241

Table G1

Predicted Time to Burn Injuries

Sensor Name	Total Heat at 2nd Degree Burn Calorie/cm.sq.	Time at 2nd Degree Burn Seconds	Time at 3rd Degree Burn
Leg, left bottom rear	5.196	55.4	68.0
Head, right eye	1.678	3.8	10.0
Head, left eye	1.598	3.3	8.0